Evaluation of Recycled Aggregate for Using in Structural Concrete

By:

Biniyam Getahune

A thesis submitted
To
Addis Ababa Science & Technology University
College of architecture and civil engineering
School of post graduate studies

In partial fulfillment of the requirement for degree of Master of Science
In Structural Engineering
Addis Ababa science & Technology University

September, 2017

CERTIFICATION

I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa Science and Technology University a dissertation entitled "Evaluation of Recycled Aggregate for Using in Structural concrete" in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering specialized In Structural Engineering .

Dr. Temesgen Wondimu

Principal Advisor

DECLARATION AND COPY RIGHT

I Biniyam Getahune, declare that this thesis is my own original work that has not been presented and will not be presented by me to any other University for similar or any other degree award.

____

Signature

Acknowledgement

First and foremost, I would like to thank God, without whom none of this would be possible. The composition and undertaking of this paper would have been nothing short of impossible without the support and contributions of so many people whose names may not be all mentioned.

I would primarily like to acknowledge my father Getahun Belete and my mother Fanose Assefa whose undying encouragement helped me greatly through the tough journey. I want to give thanks to my entire family and my friends for offering their moral, financial and physical support.

I would also like to mention my advisor Dr. Temesgen Wondimu for giving me knowledgeable advisory and sharing his wisdom tirelessly. I extend the deepest of gratitude for your kindness. You were always humble and ready to help at any time necessary.

Last but not least I would like to thank Ephrata Leulseged for always offering your succor and assistance whenever I needed it.

Abstract

In this thesis, the properties of three types of recycled aggregate in terms of impurity content and their effects on the workability and compressive strength of concrete in Ethiopia is studied. A demolished concrete sample aged 10 years is used as a source for the recycled aggregates. By using different cleaning procedures which includes chemical treatment, the recycled aggregate specimens were divided in three. The prepared specimens were: ILO, which was raw crushed demolished concrete. ILT, which is ILO but whose attached mortar residue was cleaned by a chisel and a hammer. And ILTE, which is ILT washed and cleaned with 35% diluted Hydrochloric acid. Tests, such as sieve analysis, specific gravity and absorption, moisture content, and workability are conducted to examine the quality of the aggregates. Mainly 7-day compressive strength tests were performed on (15x15x15) cm concrete cubes are prepared from the aggregates and from that the 28-day compressive strength values are projected. Theories on how and why the recycled aggregates differ from fresh ones were developed. Results show that it is possible to achieve a mix which is possible to be used in structural members using recycled aggregates. Recommendations on using recycled aggregates and ideas on how to make them cost effective are also discussed.

Table of Contents

List of Tables

List of Figures

CHAPTER I

1. Introduction

Aggregates are one of the key ingredients used in concrete, thus, in the world of construction. For instance, it takes about 50% of an ordinary C-25 concrete mix by volume. As the design life of these concrete structures is due, we will be forced to maintain or when that does not work abandon and demolish these structures. Other factors forcing us for this effect are the different natural disasters that happen time to time. Here is where the study of recycled aggregates comes in handy. Recycled aggregates are aggregates that are reusable once they have been deconstructed.

Since many regions in Ethiopia lie in earth quake prone areas and also the design life of most structures does not exceed from a range of 50 to 100 years, the proper disposal of construction wastes mainly composed of the demolished rubble of these structures can be a headache for the infant economy of Ethiopia in the near future.

1.1. Research Questions

In order to precisely meet the objectives of this study, it was important to develop research questions that directly relate to the problems. These were:

- Is using recycled aggregates cost effective compared to fresh ones?
- What is the compression strength that can be gained while using recycled aggregates?
- How does the behavior of concrete produced from waste concrete aggregates differ from concrete cast from fresh aggregates?
- How workable is concrete produced from waste concrete aggregates?

1.2. Statement of the Problem

Aggregates are one of the five main ingredients that make up reinforced concrete structures. Not only that, they are the most responsible parts in giving reinforced concrete its required strength. But once they are used in casting concrete members and then demolished their disposal brings about numerous economic and environmental problems. This research has investigated how aggregates found from demolished concrete structures can be re-used for making structural concrete in Ethiopia.

1.3. Significance of the Study

Environmental protection concerns are the burning issues of the 21st century. Every professional and academic discipline has got the responsibility to protect the environment and preserve comfortable living conditions for the generations to come. Unfortunately, very little has been done in this aspect if we scrutinize the recycling of construction wastes in Ethiopia.

This study recommends ways to recycle demolished concrete parts in Ethiopia rather than disposing them irresponsibly on open spaces around the city. Given the premises, this issue will be a crucial matter in the near future if we don't prepare for it in advance.

In an innovative and industrialized world new construction materials are being developed every day. Hence, it will be wise to update the classics (Reinforced Concrete) and help maintain its merits over newly discovered materials. The research also intended to add a considerable amount of knowledge based on experimental study about related practices in Ethiopia.

1.4. Objectives

The main objective of the thesis is to study the structural behaviors of concrete produced from recycled aggregates and recommend on how aggregates obtained from demolished reinforced concrete materials could be used for structural purposes in Ethiopia. On the way of attaining the above mentioned main objective, efforts were put to meet the following sub-objectives:

- Compare and contrast between the structural properties of concrete composed of recycled aggregates and those of fresh aggregates
- Study how the compressive of the concrete changes while using recycled aggregates
- Suggest ways which will help in adopting practices in other countries with better experience in the area
- Check if the use of recycled aggregates for structural concrete could be an economical solution for waste concrete parts in Ethiopia

CHAPTER II

2. Literature Review

2.1. What are Aggregates

In order to understand and do an ample research on recycled aggregates, it is crucial to fully understand what aggregates are. This is due to the fact that the structural behaviors of recycled aggregates must be in adequate proportions to that of fresh ones for them to put to structural purpose.

Aggregates are granular materials used in construction work. They are the most mined materials in the world. They are a component of composite materials such as concrete and asphalt concrete. The aggregate serves as reinforcement to add strength to the overall composite material, hence making it a very important component mostly responsible for the strength of the mix. For the purpose of this research we will focus only on its use as a structural element in concrete.

2.2. Where do aggregates come from

The main sources of the aggregates that we use in the construction industry are first mined from the earth's surface. Which after they will be cleaned and crushed to attain desired shapes and sizes to make them convenient for construction purposes. At the same time there are also ways of artificial production of aggregates. And also these days the concept of recycling aggregates is being studied closely by different scholars around the world.

Aggregates are obtained from different places, which make them to have different geographical origins. This can affect the properties of the aggregates which will in turn be displayed in the fresh and hardened properties of concrete in multiple ways. Below, we will try to see the different sources of aggregates and their expected properties for general understanding of this issue.

The three major types of natural aggregates sources are:

1. Sedimentary Rocks
2. Igneous Rocks
3. Metamorphic Rocks

Generally sedimentary rocks are not the best sources for aggregates which are used for construction purposes. Of the sedimentary rocks, hard dense limestone and dolomite generally make good sources of crushed stone. However, some limestone and dolomite may be soft, absorptive, and friable, which results in poor quality aggregate. Chert and flint may be used as crushed stone; however, they are hard to crush and may cause adverse chemical reactions when used as concrete aggregate. Usually sandstone, when hard and dense, is most commonly used for crushed stone and is a major source of aggregate in some areas.

Igneous rocks commonly are hard, tough, and dense, and make an excellent source of crushed stone. However, certain extrusive rocks are too porous to make good aggregate and other highly siliceous igneous rocks tend to chemically react with alkali when used as aggregate in cement concrete. Fractures along cleavage in some coarse grained igneous rocks can result in crushing strengths too low for aggregate use. For the same reasons some lava flow rocks may be unsuitable for aggregate if they contain flow-banded, strongly jointed, vesicular, or brecciated members.

Metamorphic rocks consist of many types of rocks. They are also not a common source of aggregates in the construction industry.

A variety of properties can be described to characterize aggregate. Many of these are physical properties that can be measured using standardized tests. Chemical properties of aggregate are important in the manufacture of concrete because some aggregates contain minerals that chemically react with or otherwise affect the mixes.

Excessive amounts of contaminants may cause decreased strength and durability of aggregate, may affect the quality of the bond between the cement and the aggregate, may cause an unsightly appearance, and may inhibit the hydration of the cement.

Therefore, while in the process of recycling waste concrete aggregates we must make sure that we reduce the amount of contaminants to a minimum. This will insure an improved structural properties of the concrete we will cast with the recycled aggregates.

The physical and chemical properties of aggregate result from the geologic origin and mineralogy of the potential source and its subsequent weathering or alteration. Many of the properties of aggregate relate to grain size, texture, mineralogy, pore space, and weathering products.

Aggregate characteristics can be divided into three groups:

(1) Physical properties,

(2) Chemical properties, and

(3) Contaminants.

This study focused mainly on evaluating the physical properties of the recycled aggregates and on dealing with the different contaminants that affect the structural performance of the aggregates. The chemical properties of the aggregates are more relevant for selecting types of stones to crush in making aggregates. And since the aggregates used for this study were firstly approved from their quarry for construction use, we are not going to emphasis on the chemical properties of the aggregates.

Major physical properties that affect the use of aggregate with Portland-cement concrete are: gradation of particle sizes; particle shape; particle-surface texture; porosity; pore structure; specific gravity; thermal properties; and susceptibility to volume changes. The presence of certain contaminants can prevent the cement from hydrating or bitumen from adhering to the aggregate.

2.3. Environmental impacts of demolishing concrete structures

Most projects, especially those that have relatively huge sizes are given a go after their impact over the environment is studied prior to their construction. Even though this approach is not widely implemented in our country, it is expected that its followed while national projects are underway.

In a construction industry like the one in our country, environmental effects of civil engineering works are becoming an important issue day by day. Where construction of public houses (condominiums) is intensely on progress and at the same time knowing the short design life of this numerous structures, it is only very wise to think and prepare for the adverse pressure they put on our environment in the near future.

2.4. Safe disposal methods of demolished concrete

Construction waste consists of the amount of unsolicited demolished or cart away material that is produced directly or indirectly from construction process. It is not very uncommon to see a number of structures being demolished around Addis Ababa, the capital city of Ethiopia. And for professionals working closely in the discipline, the amount of construction material wastes from mixing plants and other construction activities is not an amount to be ignored. The usual practice to get rid of these wastes is by dumping them on different disposal sites.

Typical waste components include Portland cement concrete, asphalt concrete, wood, drywall, asphalt shingles, metal, cardboard, plastic, and soil. This waste material has only recently gained attention as concerns about its environmental impact have developed. Recycling of aggregates could make a massive contribution to the construction industry. Recycling is often pursued as the most environmentally preferable method for managing construction and demolition debris.

2.5. Recycling demolished concrete aggregates

These days the concept of recycling aggregates obtained from demolished concrete structures is widely being practiced in countries which have a developed construction industry. This practice can be very useful in rebuilding countries that have been through some intensive wars where civil engineering structures have been demolished as a result.

Recycling of demolished aggregates can cover a wide range of applications between using recycled aggregates for sub base fill with minor treatments to structural construction purposes by applying a series of treatments to make it adequate for the intended aim.

Load bearing members of buildings are highly important for the safety of a structure. They need to achieve specific structural properties to be able to serve the purposes they are designed for. Even though it takes an intense cleaning and preparing procedures, it is believed that we can use recycled aggregates for structural purposes. That leaves us with the question “how can we best prepare recycled aggregates for structural uses?”.

2.6. What Are Recycled Aggregates

The need for recycling arises in many industries because there is necessity to reduce production of material and manage waste in both cases attaining the more economical and environmental friendly approach.

Even though there is an absence of specific data, it is now very usual to see demolished buildings in the capital city of Ethiopia. Especially for professionals working closely in the construction area, it is a show in day light to witness the large volume of construction industry wastes. In the construction industry, it is practical to convert this massive amount of waste concrete in to resource.

Recycled aggregates come from reprocessing materials that have previously been used in construction. They are produced by crushing concrete, and sometimes asphalt, to reclaim the aggregate.

2.7. Some Studies on Recycling Aggregates

Destructive surrounding materials around concrete structures can penetrate and be a reason to making concrete to flake off causing it to have a shorter healthy life time. When it comes to suitability of use of concrete casted with recycled aggregates for structural uses, the issue of durability is found to be an important factor to be considered. A concrete member that can easily flake around the edges and leave the reinforcing bars without any protection from corrosion is clearly not recommended for structural uses.

Levy et al. (2004) wrote a paper with the title "Durability of recycled aggregates concrete: a safe way to sustainable development" which tried to explain how using recycled aggregates can affect the durability of the members. The recycled aggregates they used for their study were obtained by passing old concrete and masonry through a jaw crusher. From that, the resulting product was subjected to a sieving operation where the crushed aggregates after sieving were used to produce 12 concrete families in a controlled environment. Then they compared the results to another specimen which was cast purely from fresh natural aggregates.

After this samples were cast, they were given 28 days to reach their optimum compression strength and also so that they could show realistic properties on the desired tests. Then they performed compressive strength tests, water absorption testes, total pores volume and carbonation depth tests by conventional laboratory methods to have an idea of the durability properties the samples exhibit. They concluded even at a complete replacement of fresh natural aggregates by recycled aggregates, the concrete specimens showed satisfactory durability and workability properties as compared to the specimen cast from all fresh natural aggregates. Considering in mind that the availability of contaminants in the samples they used, this was an important finding.

Malešev et al. (2010) in their paper entitled "Recycled Concrete as Aggregate for Structural Concrete Production" presented a comparative analysis of the experimental results of the properties of fresh and hardened concrete with different replacement ratios of natural with recycled coarse aggregate.

The recycled aggregate was prepared by crushing the waste concrete of laboratory test cubes and precast concrete columns. After that, three concrete prototypes were prepared for experimental tests: one made entirely with fresh natural aggregate as a control concrete prototype and two types of prototype prepared from fresh aggregate with 50% and 100% percentage of recycled concrete aggregate.

The main objective of this study was to compare the basic properties of concrete made with fresh aggregate and the properties of concrete made with different percentages of recycled aggregate. Cement content, maximum grain size (32 mm), and type and quantity of fine aggregate were among the factors which were kept constant through all the sample concretes prepared for the experimental investigations on their study. The fine and coarse fresh aggregates were originated from a local river and dominantly consist of quartz grains. The sources of the fresh aggregates are believed to be of a factor in achieving the desired properties of concrete even though it might not be in significant levels.

C30 concrete cubes and C40 precast columns were first crashed with a pneumatic hammer and then further crushing was performed using a rotating crusher to obtain the recycled concrete aggregate samples for the experimental investigation.

Taking a look at results they have obtained from the compressive strength tests, they were able to see that all prepared samples relatively have the same compressive strength change as a function of time with a negligible difference of compressive strength values between the different types of samples prepared for tests.

With some extra effort on the preparation of concrete produced from recycled concrete, it was possible to get a concrete mix which has sufficient workability for ease of use as the mix prepared from fresh natural aggregates.

Unlike some other studies, this study was able to conclude that the type of coarse aggregate has no effect on the air content in concrete based on the performed experimental tests. This difference of outcome can possibly be the result of procedures followed in preparing the recycled concrete aggregate sample.

As a summary of their study, they were able to conclude that regardless of the replacement ratio, recycled aggregate concrete (RAC) had a satisfactory performance, which did not differ significantly from the performance of control concrete in this experimental research. Not only in terms of the mechanical properties, but also the other requirements related to mixture proportion design and production of this concrete type. The only two properties those are lower than for the natural aggregate concrete properties were the modulus of elasticity and shrinkage deformation. However, for this to be fulfilled, it is necessary to use quality recycled concrete coarse aggregate and to follow the specific rules for design and production of this new concrete type.

As stated, the samples are obtained from concrete prepared in the laboratory for different tests. This can be taken as the limitation to the study because these samples might have less contamination than the concrete samples that can be obtained from demolishing structures on site.

Topcu et al. (2002) were two researchers at the civil engineering department of the Osmangazi University in Turkey who tried the recycling of as an environmentally friendly approach to the disposal of waste from construction activities. They used the premise of visual inspections done by numerous experts that waste concrete aggregates could be made use of as ingredients in the production of concrete.

The aim of their study was to produce C16 and C20 quality concrete with waste concrete aggregates. The newly produced laboratory test samples contained 30%, 50%, 70%, and 100% of waste concrete coarse aggregates in the place of the fresh natural aggregates to determine the optimum ratio of these two materials to produce a concrete that displays satisfactory performance for various civil engineering uses. The waste concrete aggregates were obtained by crushing C14 cylindrical concrete samples the researchers prepared to sources.

We can also see here that the sources for the waste concrete aggregates are obtained from crushing very young and not realistically loaded concrete samples as opposed to the source materials we can acquire when we try to apply this concept practically in the everyday construction activities.

They have performed both fresh and hardened concrete tests on concrete prepared from waste concrete aggregates of a maximum grading size of 31.5mm. The hardened concrete tests were performed on concrete cubes of 28-day air cured samples.

Lower specific gravity, lower fresh and hardened unit weight and less workability were notice in the increased ratio of waste concrete aggregates in the test samples. These properties are all coherent with reports from other publishing's reviewed in this research paper.

At the end they believed it was possible to produce concrete of C16 quality by using waste concrete aggregates obtained from a C14 crushed cubes but not exceeding an amount of 30% of waste concrete aggregate. They also recommended that waste concrete aggregates could be used as protective barrier and ground-filling material against erosion.

Katz (2001) was a researcher in at Israel institute of technology. In 2001 he was motivated to study the different properties of concrete made with recycled aggregate from partially hydrated old concrete. He used concrete having a 28-day compressive strength of 28 MPa crushed at ages 1, 3 and 28 days to serve as a source of aggregate for new concretes. Which after the properties of the recycled aggregate and of the new concrete made from it, with nearly 100% of aggregate replacement, were tested. His samples were taken from concrete test cubes made to test the qualities of the cement used in preparing them by cement manufacturing companies for the purpose of standard assurance. Immediately after the compression tests were made by the companies, the cubes were crushed by a mini jaw crusher and dried in an oven at 105°-C to inhibit any further hydration.

His experimental program involved two phases which were to study the properties of concrete made from recycled aggregates that were obtained by crushing partially hydrated old concrete the effects the recycled concrete aggregate displays on the properties of the newly casted concrete.

He creatively used white cement in the concrete casted from recycled concrete aggregates to try and observe if any visual distinction is available in between the new cement matrix and the one that is left sticking after the crashing of the concrete cubes in the production of the recycled concrete aggregates while preparing his experimental test samples. However, it was found later that it is impossible to define, even under the microscope, a clear boundary between the new cement matrix and the recycled aggregates. The test cubes were then in water cured for 7 days and air cured until their testing day.

He suggested that as long as the settings of the crushers are adjusted in consistency with the design output, there is no significant difference in the grading of the recycled aggregates relatively with the fresh crushed material.

The concrete prepared from the recycled concrete aggregate displayed a higher air entrainment and as a result a lower density as compared to the control sample. He was not clear on the cause of the increased air content and recommended for further studies to be conducted in the area to understand this phenomenon in advance.

The workability of the fresh recycled aggregate concrete was sufficient for optimum uses after the inclusion of natural sand in the mixtures. But this property is not satisfactory when both recycled fine and coarse aggregates are used for the fresh concrete mixture.

In his observations of the properties of recycled aggregate concrete in hardened stages, he stated that crushing age is an important factor to attain a relatively close compressive strength in comparison to the control sample. The 1 day samples showed a 40% to 50% decrease in compressive strength in relative to the compressive samples. At the same time, differences in flexural and splitting strength were both kept under 20% in relative to the control samples. This value can be considered a practicable margin.

Interestingly, he was able to attain a 9.5MPa compressive strength by casting a concrete cube which no additional cement was used. That means directly using the fine recycled aggregates obtained at the end process of the concrete crushing. This value can be taken as a hint that with some modifications in the production of the concrete, it can be achievable to make structural use of concrete prepared from recycled aggregates.

Other conclusions of this study were lower modules of elasticity, higher absorption rates and carbonation depths.

At an early age the recycled aggregate is weak, but it rapidly gains strength with age. Additional hydration of the old cement in the recycled aggregates may somewhat improve their properties when they are embedded in the new concrete, mainly of those crushed at age 1 day.

2.8. Crushed returned concrete

Crushed returned concrete is a term used for concrete obtained from crushing the returned concrete that was discharged at the concrete plant and left for a period of time before crushing.

Also this type of waste concrete is available nearly in all construction sites in Ethiopia as a result of poor resource management and lack of appropriate equipment's to reduce such wastage.

Therefore, this aggregates are not really used in structural purposes thus were not exposed to loads that can degrade their structural properties. But still, these aggregates have gone through the chemical reactions that make them to be contaminated to be used as freshly produced aggregates for structural purposes. This process is believed to affect the structural behavior of the crushed returned concrete adversely.

The compressive strength of the concrete mixed from recycled aggregates also can depend on the properties of the original concrete. This can be due to a number of reasons like the use of admixtures in the making of the original concrete.

Kim (2009) conducted a study with the title "Crushed Returned Concrete Aggregate in New Concrete: Characterization, Performance, Modeling, Specification, and Application". The objective of the research was to develop technical data that will support the use of the CCA aggregates from the returned concrete by the ready mixed concrete industry.

The main advantage of preparing crushed returned concrete aggregate for use in new concrete is the fact that there is a very minimum chance that the CCA is contaminated. In addition, the study investigated how the high absorption capacity and specific gravity of the CCA helps in using it as a curing agent in concrete. The results obtained in compressive strength were encouraging since it was in a range of 97% to 78% in comparison to the control cubes. The study proposed that mixing crushed returned concrete aggregates up to 10% of the total aggregate volume in new concrete should be allowed because the mix can exhibit satisfactory structural properties.

CHAPTER III

3. Methodology of the Research

The initially proposed methodology to test the structural properties of the concrete that is obtained from demolished concrete parts was to take the samples in to a crushing quarry to clean the aggregates from different types of impurities. This includes crushing to remove fine aggregates and cement attached on the aggregate parts.

But when it came to practical implementation of the proposed methodology, it was difficult to see through the plan with the limited availability of sample materials and the size of the crushing machine which will make it impossible to obtain a significant amount of cleaned aggregate at the end of the process. As a result, a smaller crushing machine is proposed to attain the intended results.

As these demolished concrete parts are not usually demolished with the thought of recycling them they can usually get mixed with other rubbish materials which can affect the desired structural properties of concrete adversely. Therefore, the first step to take before developing any models is to thoroughly clean the acquired sample from any contaminant materials.

I. Approach

To attain the listed objectives, the following methods were followed. The problem solving approach methods are chosen because they are found economical directly linked to the desired properties to be studied and realistic in comparison with the allocated budget to this project. They are comprised of data mining and experimental observation techniques.

Therefore, the researcher has:

- Reviewed and analyze previous literature related to the topic
- Developed models to study the properties of concrete produced from recycled concrete aggregates.

This is done mainly by observations of laboratory tests which reflect the structural behaviors of concrete and the material properties of aggregates. Hence, we have tried to select specific laboratory tests which can reflect the desired structural properties of the concrete cast from recycled aggregates. These testes that were performed are listed below with their procedures as conducted under this research.

1. Compressive Strength test
2. Sieve analysis of Course Aggregates
3. Unit Weight of Course Aggregates
4. Specific Gravity and Absorption Capacity
5. Moisture Content of Aggregates
6. Workability or Slump test

All test methods followed EBCS specifications.

NOTE: Standard test procedures followed in this study are listed in **Appendix A**

II. Preparation of Recycled Aggregates

First the demolished concrete parts were obtained from a ground plus three residential building which was constructed ten years ago. The structure was demolished by the owner's decision to use the plot for commercial purposes.

The samples collected have been giving normal residential services throughout its life time. Hence, it has been loaded and exposed to realistic residential activities making it an ideal source of specimen for this study.

Using these source materials, the tests were performed on recycled aggregate with three impurity levels, which were prepared with the following methods.

Recycled Aggregate Sample One: Manually (Broken in to pieces by a hammer and chisel) crushed recycled aggregates

Recycled Aggregate Sample Two: Recycled aggregate sample one that has passed through a partial manually cleaning process with a hammer and a chisel to specifically remove mortar and other attached impurities.

Recycled Aggregate Sample Three: Recycled Aggregate Sample One that has passed through a chemical treatment with Muriatic acid (35% Hydrochloric Acid) in order to clean attached mortar and other impurities.

CHAPTER IV

4. Results and Discussion

The three different levels of impurities were all prepared by adding extra procedures to get a specimen that contains a reduced amount of contaminants per level. The detail process of the preparation of the samples is discussed in the coming three paragraphs.

The source building was demolished using a jack hammer. As a result, the collected demolished concrete parts had a relatively large size. It was necessary to crash them to smaller pieces to arrange for them to have convenient sizes for laboratory tests. They were then crushed manually by a direct impact using a 2 Kg hammer by visually inspecting the sizes of the aggregates to have approximate sizes which will not adversely affect the following tests. Then after the debris and worn off mortar parts that have fallen of the surfaces of the aggregates were selected by hand and removed from the bunch. This stage marked the complete preparation of the first sample. It was set aside and labeled Impurity Level One Specimen or ILO.

Figure 1A: Raw Demolished Concrete (Left)   Figure 1B: ILO Specimen (Right)

The second specimen of recycled aggregates which is prepared to be subject to laboratory tests is called Impurity Level Two Specimen or ILT. This specimen was designed to exhibit appreciated properties because of the extra treatment efforts put into action. To remove an additional amount of physical contaminants adhered on the surface of the aggregates a traditional cleaning method was implemented. The mortar and other contaminants were cleaned manually by a 2 Kg hammer and a chiseling rod. With a continuous and careful effort to singly point and clean the extra adhered mortar, it was possible to obtain a relatively cleaner specimen. After the process, it was noted that this particular sample has lost 25 percent of its mass as a result. It was also possible to visually understand that there were finer particles in this specimen as a result of the cleaning procedure.

Figure 2: ILT Specimen

On the last and third specimen, aggressive treatment measures were taken. This was due to the researcher's intention to cover a large range of impurity level content in the matter. Muriatic Acid, a 35 percent diluted Hydrochloric acid (HCL) was used to treat the specimen in to a reduced level of chemical and physical impurities. This acid has similar properties to the digestive HCL in the human digestive system but a more concentrated solution is used for treating the aggregates. The step by step procedure is as follows:

Materials Needed:

- Two Plastic cans with a minimum capacity of 10 Liters
- 5 liters of HCL 35%
- Two Clean Wooden Steering Sticks Long enough for reasonable precautions for keeping a fair distance from the mixture
- Two pairs of protective gloves
- Demolished Aggregate Sample to be treated (ILT)

Procedure

Step 1: Wash the aggregate Sample in the first can and get rid of primary impurities

Step 2: Clean and prepare the Plastic can and put the aggregate sample in the can first to avoid spilling of the cleaning acid on surrounding surfaces

Step 3: With the necessary protection tools in place, Slowly Pour the HCL acid in the plastic cans that contains the sample aggregate with extra caution

Step 4: At this stage, leave the mixture as it is for one hour for the acid to weaken the attached mortar and any other contaminants present

Step 5: After an hour of wait, Take the Steering Stick and mix the two ingredients together by strategically rubbing them against the wall of the plastic cans to cause flaking of adhered contaminants for 15 minutes

Step 6: Take another 30 Minutes break before moving to step 7

Step 7: Apply another 15 minutes of strategical rubbing between the steering stick and the wall of the plastic can

Step 8: Close the container with a cover to protect it from further contaminates and let it still over night

Step 9: Apply a final 15 minutes rubbing and clean the aggregates thoroughly with water repeatedly

Step 10: Dry the specimen on day light

Note: All Steps should be carried out in open air environment to avoid unnecessary inhaling of chemicals in the absence of respiratory protection tools.

After undergoing this step by step procedure, we acquired the final specimen ready for laboratory tests and labeled it Impurity Label Three (ILTE)

Figure 3: ILT sample Prior to Cleaning

Figure 4: Cleaning with Hydrochloric Acid by Stirring

Figure 5A: ILT Sample After Cleaned(Left)   Figure 5B: Residue

Figure 6: ILTE Specimen

4.1. Workability or Slump

The workability of fresh concrete is an important property which can influence the applicability of a certain mix for structural use. There are specific recommendations to where the use of a certain type of mix is appreciated just by depending on the value of the slump of a fresh concrete. If we first see the two extremes, we usually are recommended to use drier mixes with low slump for road construction and concrete with high slump for conditions where it is hard to easily vibrate structural members.

The down side in trying to control the slump of a mix is that it will alter other very important properties like the required water cement ratio of the mix which will in turn will cause difficulties in attaining our desired strength of the concrete. As a result, the materials we use as ingredients to cast the concrete are expected to meet a certain range of slump to be in effect structurally.

Below is a graph showing the slump of the three samples under this study.

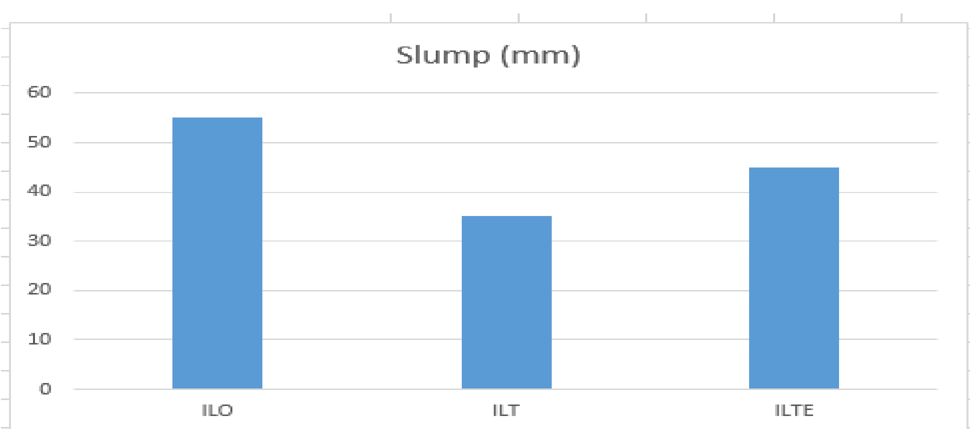

Figure 7: Slump of tested Specimens

NOTE: From left to write is a relatively decreasing content of impurity

As the results imply, samples prepared with ILO and ILTE recycled aggregates has very satisfactory slump values. While the concrete prepared from ILT has shown a slump of 35mm. This is due to the high shape alteration of the recycled aggregate as a result of adhered mortar and the impact of the hammer cleaning procedure. Consequently, the slump values of ILO and ILTE were found to be 55mm and 45 mm respectively. This implies the Hydrochloric acid cleaning of specimen ILTE has caused the slump to be improved significantly.

4.2. Specific Gravity

The specific gravity of the aggregates is the relative density of the aggregates in relative to that of water. Aggregates have tiny pores in them, that allows for the reduction of its density in significant values, mostly in light weight aggregates. Specific gravity of a normal weight coarse aggregate is around 2.6.

Specific Gravity values of the tested specimen are as follows:

Specimen ILO: 2.43

Specimen ILT: 2.4

Specimen ILTE: 2.55

This shows that specific gravity decreases with higher impurity content. This is due to the low specific gravity of the attached mortars dialing down the gross specific gravity of the recycled aggregates. When this value is reduced below 2 we will approach to conditions that will force us to use these aggregates for light weight concrete uses only. This will also decrease the maximum compressive strength that could be achieved by using recycled aggregates.

4.3. Grading of Recycled aggregate

This property controls the workability of the fresh concrete mix. The cement is the costliest ingredient in concrete. Therefore, an evenly Graded coarse aggregate can ideally fill in spaces well and minimize the paste required. For this effect to work, aggregates are not encouraged to have relatively uniform sizes.

The maximum aggregate size on the ILO specimen tends to be greater than the other two specimens. This is due to the raw demolished concrete is broken in to visually acceptable size by a direct impact of a 5kg hammer. This caused the creation of aggregate particles that have a relatively large amount of aggregates larger than 40mm and also on the flip side particles that are really fine.

Below is a graph prepared using the sieve analysis data of the specimens.

Figure 8: Combined Sieve analysis chart

In the middle range, we can see that there is a fair distribution of aggregate grading which is very important in reducing the amount of paste used in concrete. Therefore, this even distribution of particle sizes reflects on better structural properties and economic implications.

4.4. Moisture Content

This is a very important effect in determining the water cement ratio of the concrete mix. All aggregates contain certain amount of moisture due to different reasons including storage conditions and the material properties of the source material. Due to attached mortar residue, recycled aggregates are expected to have higher moisture content than fresh aggregates. The moisture content can range in between one percent in gravel up to fifteen percent in materials with very pours surfaces, considering the aggregates are normal weight aggregates.

The three tested samples in this study had the following moisture contents:

Specimen ILO: 2.6%

Specimen ILT: 2.4%

Specimen ILTE: 2.32%

To simply see the relationship between the moisture content of the three tested samples, let's look at the graph below.

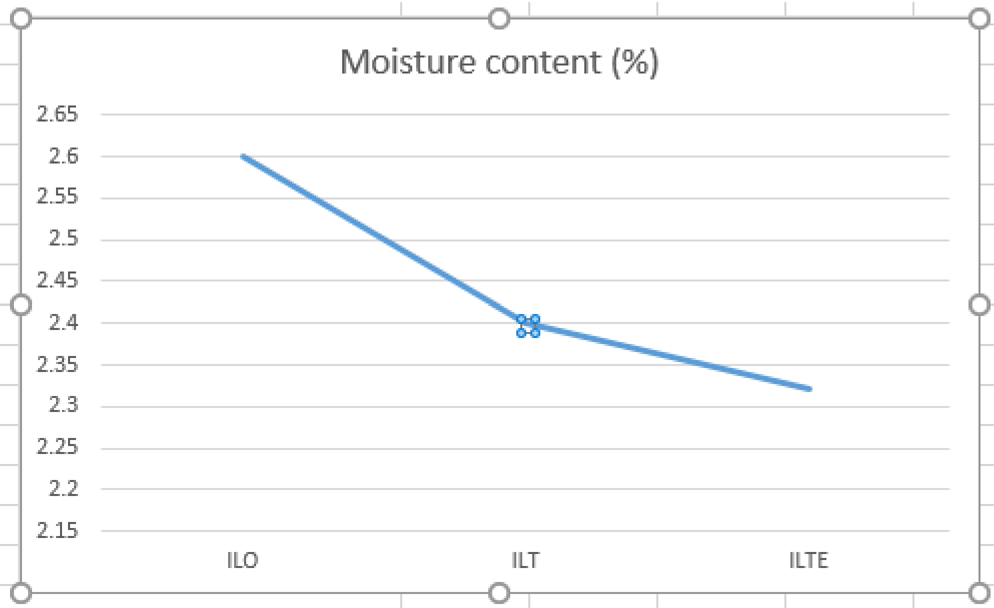

Figure 9: Moisture contents of specimens ILO, ILT and ILTE

The moisture content is decreasing from Specimen ILO, ILT to ILTE sequentially. The order is given in an ascending manner with respect to cleaning efforts. Therefore, we can see the effects of cleaning the contaminants out of the recycled aggregate samples in order to reducing the moisture content. The presence of higher moisture content in the aggregate will lead to the reduction of water inserted in the mix. As a result, it will cause difficulties in keeping the workability and water cement ratio of the mix in parallel for the best results.

Any additional physical efforts to remove the adhered mortar off the recycled aggregates can cause an uneven grading and also for greater mass loss of the aggregates in turn increasing the probability of using recycled aggregates uneconomical. Therefore, if any additional engagements are to be made to that effect, we highly recommend chemical treatments to take place. This can be by using a more concentrated Hydrochloric acid or by adding extra repetitions on the chemical treatment procedure used in this study.

4.5. Absorption Capacity

Coarse aggregated stored in a pile usually has an absorption that is around one percent. Even though it is not a problem in coarse aggregates, in fine aggregates the percentage can vary up to six percent. This causes the expansion in volume which can cause errors in volume proportioning of the mix ingredients.

For the same reasons as for higher moisture content, we can rationally expect higher numbers of absorption capacity in the recycled aggregate specimens. We can look at the graph below to see the relationships between impurity content and absorption capacity.

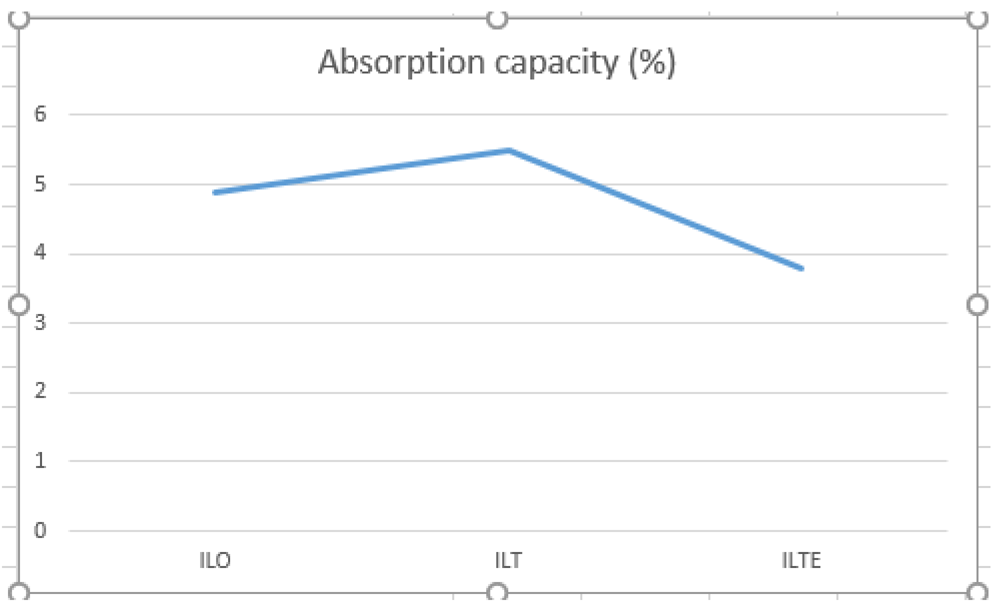

Figure 10: Absorption Capacity

We can notice that the absorption capacity of the sample ILT is 5.5%, which is greater than absorption capacities of specimens ILO and ILTE. The reason for this can theoretically explained by the presence of more crushed mortar particles as a result of the hammer impact cleaning. And also we can notice the third specimen (ILTE) has the lowest absorption capacity. This is due to the effectiveness of the Hydrochloric acid treatment to cleaning the mortar attached to aggregate surfaces.

4.6. Compressive Strength

The compressive strength of concrete is the key structural property of concrete. It is this strong characteristics of concrete that make up the most commonly used heterogeneous structural members with the significant flexural strength of reinforcing steel. Since aggregates constitute of 60% to 80% of concrete by volume they contribute a lion share on giving the mixture desired structural behaviors.

The major concerns in the efforts to use recycled aggregates for structural purposes arises in this area. This study mainly aimed to observe the effects of the recycled aggregates on the compressive strength of concrete and how the resulting challenges could be faced in order to achieve a compressive strength of 25Mpa to enable us to use them in structural members.

The seven-day compressive strength was put under the spot light in this study. On crushing, the following compressive strength results were obtained.

Table 1: Compressive strength values of ILO5

Date Made	Date Tested	Age (Days)	Stress (MPa)	Stress (Psi)
23/08/2017	30/08/2017	7	20.4	2960
23/08/2017	30/08/2017	7	22.1	3205
23/08/2017	30/08/2017	7	21.2	3075
Average			**21.23**	**3080**

Table 2: Compressive strength values of ILT

Date Made	Date Tested	Age (Days)	Stress (MPa)	Stress (Psi)
23/08/2017	30/08/2017	7	20.4	2960
23/08/2017	30/08/2017	7	22.1	3205
23/08/2017	30/08/2017	7	21.2	3075
Average			**21.23**	**3080**

Table 3: Compressive strength values of ILTE

Date Made	Date Tested	Age (Days)	Stress (MPa)	Stress (Psi)
23/08/2017	30/08/2017	7	22.3	3235
23/08/2017	30/08/2017	7	22.3	3235
23/08/2017	30/08/2017	7	22.2	3220
Average			**22.27**	**3230**

Closely observing the numbers of the compressive strength, we can note that a significant difference comes on the compressive strength of ILTE specimen. The first two specimens ILO and ILT displayed exactly the same seven-day compressive strength. Therefore, manual cleaning of the aggregates is not to make a significant change unless we employ intensive chemical cleaning procedures.

Mindness and Young (2017), recommend that it is possible to obtain the estimate of the 28th day strength by factoring the 7th day value with 1.5. Using their theory, the average compressive strengths of the test cubes on 28-day can be estimated.

Specimen ILO: (21.23 x 1.5) = 31.8MPa

Specimen ILT: (21.23 x 1.5) = 31.8MPa

Specimen ILTE: (22.27 x 1.5) = 33.4MPa

In specimens ILO and ILT, the compressive strength tends to be somehow lower than from that of specimen ILTE. This is understood to be because of the effectiveness of the HCL in cleaning attached particles that are responsible for the reduction of the compressive strength.

Therefore, with the given procedures of preparing recycled aggregates, it is possible to come up with coarse aggregate particles that are fit to be used in structural purposes. The author recommends more studies in the area to try to achieve higher compressive strength values.

4.7. Cost Analysis

On common practice, demolished rubble of construction waste is disposed in disposal areas irresponsibly. Therefore, it is possible to get the demolished rubble free of charge. As it has been observed in this study the cost of preparing one cubic meter of recycled aggregates is as follows.

Specimen ILO

Man Power for crushing: 100 Birr

This is the total cost of the preparation, which is 20% of the cost we are charged to buy fresh aggregates.

Specimen ILT

Man power for crushing and cleaning: 200Birr

This is the total cost of the preparation, which is 40% of the cost we are charged to buy fresh aggregates.

Specimen ILTE

Hydrochloric Acid Required: 5 liters of Technical grade standard coasting 600Birr

Man Power for crushing and cleaning: 200Birr

Water: 50Birr

Protective Tools: 100Birr

These sums up to a total cost of 1050 Birr per Cubic meter

This cost is expensive when compared to the price of fresh aggregates which costs around 500 Birr per cubic meter. But this cost can be matched with the purchase of a larger volume of HCL which can reduce the fee of the chemical by up to 50%.

But it is believed that there can be a better way to prepare the recycled aggregates which can be found cost effective. On this aspect, the specimen ILT is picked because of the optimum performance structurally and its cost effectiveness.

CHAPTER V

5. Conclusions and Recommendations

To conclude, recycled aggregates are safe to use with the scope of this study. The properties they display are not exactly the same as the fresh aggregate but the reduction in performance is within acceptable limits. And with the appropriate preparation procedures, the effects of the contaminants can be reduced to a minimum.

From the result s of the study it is in the Authors belief that the use of recycled aggregates for structural purposes needs to be encouraged. Given the quality reduction as compared to the fresh aggregates, it will be wise to limit the use of recycled aggregates by structural importance and floor heights until further studies are made in the area.

It is believed that if more advanced chemical treatments which go in parallel with the cost-effectiveness of the material are applied, the structural behavior will be improved more. This will allow for the use of recycled aggregates in wider range. At the same time, it will have a very significant effect on the mindsets of the consumers in terms of using recycled aggregates since that will allow for a more visually attractive material.

In addition to that, even if the cleaning procedure using chisel and a hammer was found to be nearly effective to the chemical treatment, we recommend using the chemical treatment over it because of the shape alteration by impacts and the efficiency in terms of time.

While demolishing of structures in underway, it is recommended to prepare the environment so that the demolished samples will not me meeting any additional contaminants in the area. This could be done with a minimum cost of cleaning the site area and using a plastic cover over the floor area.

Stalking of the material on site before use should be met with cautions. The material properties of recycled aggregates tend to absorb a significant amount of water if placed in areas where it gets in contact with plenty of water. That is because of the porous property of the adhered mortar on the surface. This can lead to an inaccuracy on the water cement ratio of the mix which will in turn cause a reduction of the strength.

The author recommends further studies to be made on an even more economical preparation of recycled aggregates and ways to make recycled aggregates exhibit more enhanced structural properties which will allow them to be used in large structures.

Appendix

Appendix A: Test Procedures

A.1 Test for Workability

Objective

To determine workability of concrete

Theory

A concrete mix, either produced at a ready mix plant or on site, must be made of the right amount of cement, aggregate and water to make concrete workable enough for easy compaction and placing and strong enough for good performance in resisting stress after hardening. If the mix is too dry, then its compaction will be too difficult and if it is too wet, then the concrete s likely to be weak.

During mixing the mix might vary without the change very noticeable at first. For instance, a load of aggregate may be wetter and likely to be wetter or drier than what is expected or there may be variations in the amount of water added to the mix. These all necessitate a check on the workability and strength of concrete after producing.

Slump test is the simplest test for workability and is most widely used on construction sites in the slump test, the distance that a cone full of concrete slums down is measured when the cone is lifted from around the concrete. The slump can vary from nil on dry mixes to complete collapse on very wet ones. One drawback with this test is that is not helpful for very dry mixes.

There are three kinds of slump:

1. True slump – where the concrete just subsides, keeping its shape approximately
2. Shear slump – where the top half of the cone shears off and slips sideways down an inclined plane
3. Collapse slump – where the concrete collapses completely

The first type is associated with workable mix while the other two are usually associated with collision.

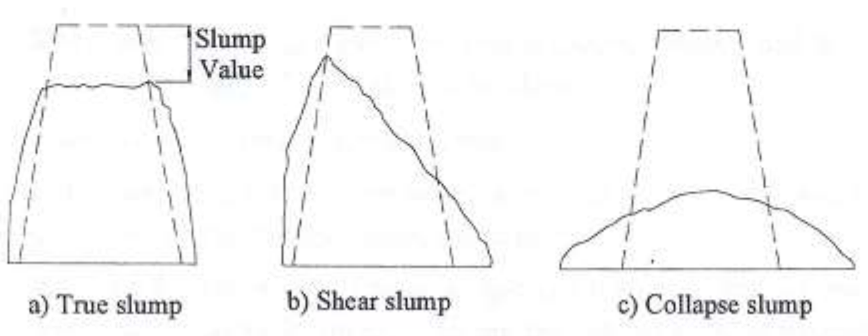

Figure 11- Types of Slump

Apparatus

- Standard slump cone - 300mm high with a bottom diameter of 200mm and top diameter of 100mm
- Steel tamping rod – 16mm diameter, 600mm long, with one end rounded
- Measuring tape or ruler
- Steel float
- Water proof plate, about 450x450 mm square

- Cleaning rags

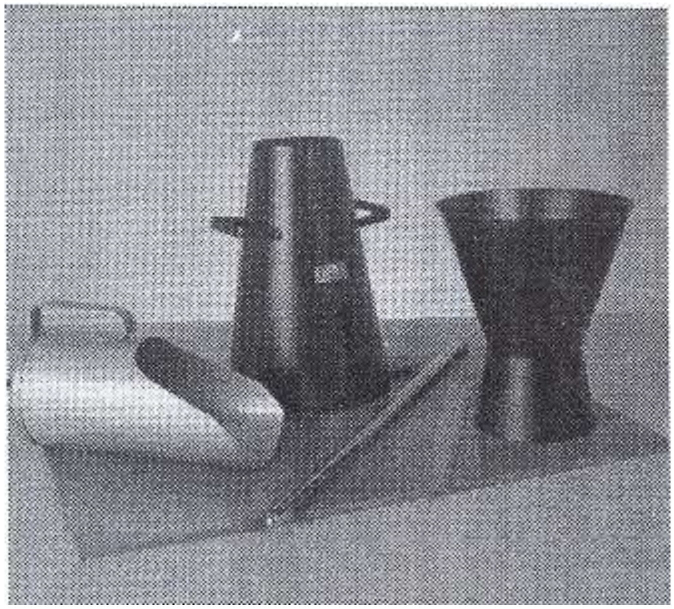

Figure 12 – Apparatus for Slump Test

Procedure

1. Make sure the cone is clean, free from hardened concrete and dry inside. Stand it on the plate, which must also be clean.
2. Stand with your feet on the foot rests
3. Using the scoop fill the one to about one third of its height and rod this layer of concrete exactly 25 times using the tamping rod.
4. Add two further layers of equal height (each about 100mm deep), rodding each one in turn exactly 25 times, allowing the rod to penetrate through into the layer below. After rodding the top layer make sure that there is slight surcharge of concrete, i.e. that some concrete out of the top
5. Strike off the surplus concrete using steel float.
6. Wipe the cone and the base plate clean keeping your feet still on the foot rests.

7. Take hold of the handles and pushing downwards remove your feet from the foot rests.
8. Very carefully lift the cone straight up, turn it over and put it down on the base plate next to the mound of concrete. As soon as the cone is lifted the concrete will slump to some extent.
9. Rest the tamping rod across the top of the empty inverted cone so that it reaches over the slumped concrete.
10. Using the ruler measure from the underside of the rod to the highest point of the concrete, to the nearest 5mm. That will be the slump.

A.2 Test for Compressive Strength of Concrete

Objective

The objective of the test is to determine compressive strength of concrete.

Theory

The major goal of concrete structures is carrying loads coming to them. These loads may be of dead, live, earthquake, wind or snow types or their combinations. The concrete produced, therefore, must not fail under actions of any such loads.

The most common test for hardened concrete involves taking a sample of fresh concrete and putting it in to special cube molds so that, when hard, the cubes can be tested to failure in special machine in order to measure the strength of the concrete.

The results obtained from compression tests on hardened concrete cubes are used to check that its strength is above the minimum specified to assess the control exercised over the production of concrete.

The strength of concrete specimen is affected by factors like water-cement ratio, degree of compaction and curing temperature. Care to be taken, therefore, in preparing samples for testing. As water-cement ratio goes up above a certain level he strength of concrete (for each 1% of air entrapped there will be a 5 to 6% loss of strength). Curing temperature affects the hydration of cement and hence the duration of strength gain (cubes kept at about 10^oC will have their 7-day strength reduced by 30% and their 28-fay strength by 15%). This calls for proper cure of test cubes at a recommended temperature of about 20^oC.

Some concrete specifications call for cylinder specimens rather than cubes. The hardened cylinders are tested either in compression like cubes or turned on their side and compressed along their diameter, causing the cylinder to split (indirect test).

Apparatus

- ⇒ Mixer
- ⇒ Cubical mold (15x15x15) cm^3
- ⇒ Vibrator
- ⇒ Spatula
- ⇒ Compressive strength testing machine

Procedure

1. Use the same concrete mix for which workability is determined
2. Prepare a cubical molds (15x15x15) cm^3 and oiled them in order to easily de molding concrete cubes.

3. Fill the concrete in the cubical mold and vibrate in order to remove air bubbles for about 30 sec.
4. Smooth the surface and remove the excess concrete on the cubes molds by using spatula, and also register mixing date at the top of concrete.
5. After 24hrs remove the concrete from the mold and cure in water till the required date.
6. Load the concrete specimens to failure at 3, 7 and 28 days of age by using testing machine and record the failure loads.
7. Calculate the stress at failure by dividing the failure loads by the respective contact areas with the load (the compressive strength) as in the table below.

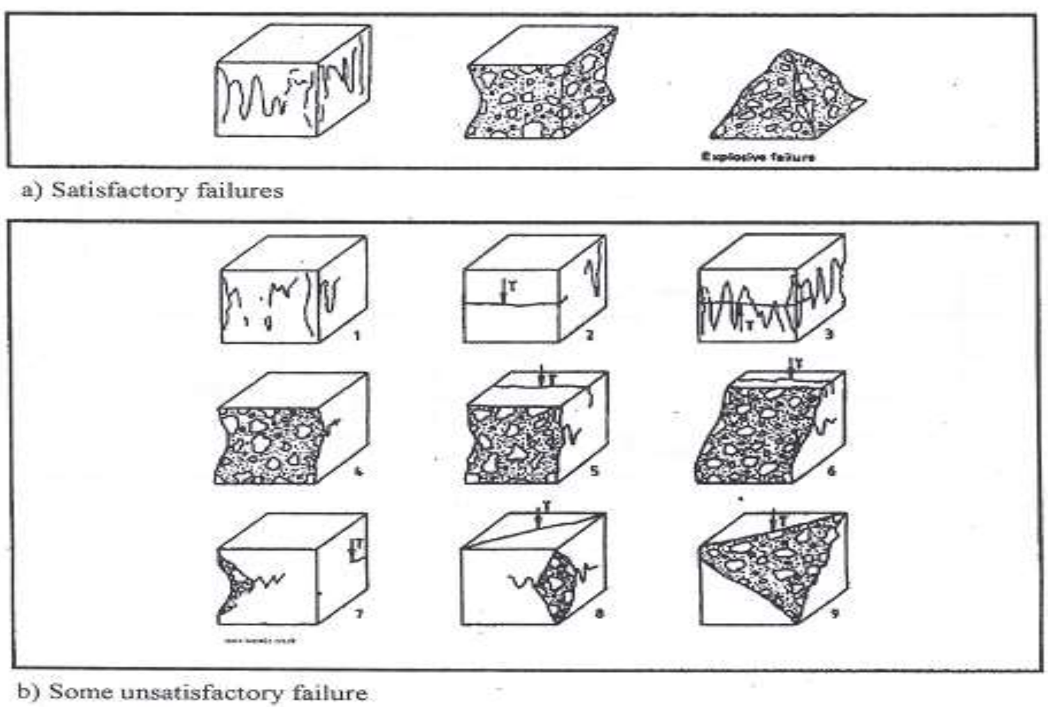

Figure 13- Satisfactory and unsatisfactory failures of concrete cube specimens

Table 4 - Computation of compressive strength of concrete

No.	Test age [days]	Dimensions (cm)			Weight (gm)	Volume (cm^3)	Failure Load [kN]	Comp. Strength [MPa]	Unit Weight [gm/cm^3]
		L	W	H					
1									
2	3								
3									
						Mean			
1									
2	7								
3									
						Mean			
1									
2	28								
3									
						Mean			

A.3 Moisture Content of Aggregates

Objective

The objective is to determine the moisture content of fine and course aggregates.

Theory

It is well known too engineers that water-cement ratio affects the workability and strength of concrete specimens. A design water-cement ratio is usually specified based on the assumption that aggregates are inert (neither absorb nor give water to the mixture). But in most cases aggregates from different sources do not comply with this i.e. wet aggregates give water to the mix and drier aggregates (those with below saturation level moisture content) tale eater from mix affecting, in both cases, the design water-cement ratio and therefore workability and strength of the mix. In order to correct for these discrepancies, the moisture content of aggregates has to be determined.

Apparatus

- ⇒ Balance
- ⇒ Dish
- ⇒ Oven
- ⇒ Trowel

Procedure

1. Weigh a sample of 2Kg coarse and 500gm fine aggregate separately (A).
2. Oven dry the samples for about 24hrs with a temperature of 105^{o} C – 110^{O} C.
3. Remove the samples from the oven and place them on the desiccator for about an hour in order to cool without absorbing water from the atmosphere.
4. Weigh the aggregates separately (oven dry weight, B).
5. Calculate the moisture content of the aggregates separately.

Calculation

$$w(\%) = \frac{A-B}{B} X100;$$

Where:

W= moisture content (%)

A= weight of original sample (g)

B= weight of oven dry sample (g)

A.4 Specific Gravity and Absorption Capacity of Coarse Aggregates

Objective

The objective is to determine bulk and apparent specific gravity, and absorption of fine aggregates.

Theory

The specific gravity of a substance is the ratio between the weight of the substance and that of the same volume of water. This definition assumes that the substance is solid throughout. Aggregates, however, have pores that are both permeable and impermeable, whose structure (size, number and continuity pattern) affects water absorption, permeability, and specific gravity of the aggregates.

Apparatus

- ⇒ Balance
- ⇒ Sample container – a wire basket of No. 6(3mm), or finer mesh, or bucket, of approximately equal breadth and height with a capacity of 4000 to 7000 m^3.
- ⇒ Suitable apparatus for suspending the sample container in water from the center of the scale pan or balance

Preparation of test sample

Select by use of a sample splitter or by quartering approximately 5Kg of the aggregates from the sample. Reject all material passing No. 4 (4.75mm)

Procedure

1. After thoroughly washing to remove dust from the surface of the particles, dry the sample to constant weight at a temperature of 110 ± 5^{o} C, cool in air at room temperature for 1 to 3 hrs., and then immerse in water at room temperature for a period of 24 ± 4 hrs.
2. Remove the sample from the water and roll in a large absorbent cloth until all visible films of water and removed. Wipe the larger particles individually. Take care to avoid evaporation of water from aggregate pores during the operation of surface-drying.
3. Weigh the sample in the saturated-surface-dry condition and record (B).
4. Immediately place the saturated-surface-dry sample in the sample container and determine its weight in water at room temperature. Take care to remove all entrapped air by shaking the container while immersed and fully immerse the test sample before weighing.
5. Dry the sample to constant weight at a temperature of 110 ± 5^{o} C, cool in air at room temperature.

Calculation

Bulk Specific Gravity:

$$\text{Bulk sp gr} = \frac{A}{B-C}$$

Bulk Specific Gravity (Saturated-Surface-Dry Basis):

$$\text{Bulk sp gr (saturated-surface-dry basis)} = \frac{B}{B-C}$$

Apparent Specific Gravity:

$$\text{Apparent sp gr} = \frac{A}{A-C}$$

Absorption Capacity:

$$\text{Absorption Capacity (\%)} = \frac{B-A}{A}\ x\ 100$$

Where:

A= weight of oven-dry sample in air, (g)

B= weight of saturated-surface-dry sample in air, (g) and

C= weight of saturated sample in water, (g)

A.5 Sieve Analysis

Objective

The objective of the test is to determine the particle size distribution of coarse aggregates.

Theory

An aggregate, for concrete making, is any hard, inert material composed of fragments in a wide gradational range of sizes, which is mixed with a cementing material and water to form concrete. Aggregates should be clean, sound tough durable and uniform in quality. They should be free of soft friable, thin or laminated fragments and deleterious substances like alkali, oil, coal, humus or other organic matter. Aggregates may be classified into two groups: (1) natural materials such as sand, gravel, crushed stone, and pumice; and (2) artificial materials, produced by crushing blast furnace or burning and crushing clays or shales. The second group includes most of the light weight aggregates. Aggregates make up 65 to 75% of the volume of concrete. Therefore, the quality of concrete produced is very much influenced by the properties of its aggregates. Aggregate grain size distribution or gradation is one among those properties and should be given due consideration.

According to the Ethiopian standard coarse aggregates are those between 75 and 4.75mm in size. Gravel, crushed rock and basalt furnace slag are generally used as aggregates.

Sieve analysis is a procedure for the determination of the particle size distribution of aggregates using of square or round openings starting with the largest. It is used to determine the grading of aggregates and the fineness modulus, an index to the fineness and coarseness and uniformity of aggregates. It is after this analysis is carried out that aggregates are described as well graded, poor graded, uniformly graded, gap graded etc. Each of the above aggregate categories has close associations with a range of quality of concrete produced using the aggregates.

Table 5 Grading requirements for coarse aggregates (ES C.D3.201)

Nominal size of aggregate, mm	Percentage passing through test sieves having square openings						
	75mm	63mm	37.5mm	19mm	13.2mm	9.5mm	4.75mm
38 – 5	100	-	95 - 100	30 - 70	-	10 -35	0 – 5
19 – 5	-	-	100	95 -100	-	25 - 55	0 - 10
13 - 5	-	-	-	100	90 -100	40 - 85	0 - 10

Table 6 Table: Grading requirements for fine aggregates (ES C.D3.201)

Sieve Size	Percentage Passing
9.50mm	100
4.75mm	95 – 100
2.36mm	80 –100
1.18mm	50 – 85
600μm	25 - 60
300μm	10 – 30
150μm	2 - 10

Apparatus

- ✓ Balance
- ✓ Series of sieves
- ✓ Shovel
- ✓ Sieve brush

Procedure for Grading Coarse Aggregates

1. Weigh 20 Kg of a sample of coarse aggregates.
2. Select a representative sample by quartering.
3. From the quartered sample take 2 Kg.
4. Weigh the empty sieves and record the data.
5. Place the 2 Kg of sample on the top sieve (having large opening size).

6. Shake the sample about 2 minutes in a sieve shaker.
7. Weigh each sieve together with the aggregate retained on.
8. Calculate the weight retained on each sieve.
9. Fill in the gradation chart as shown in the next table

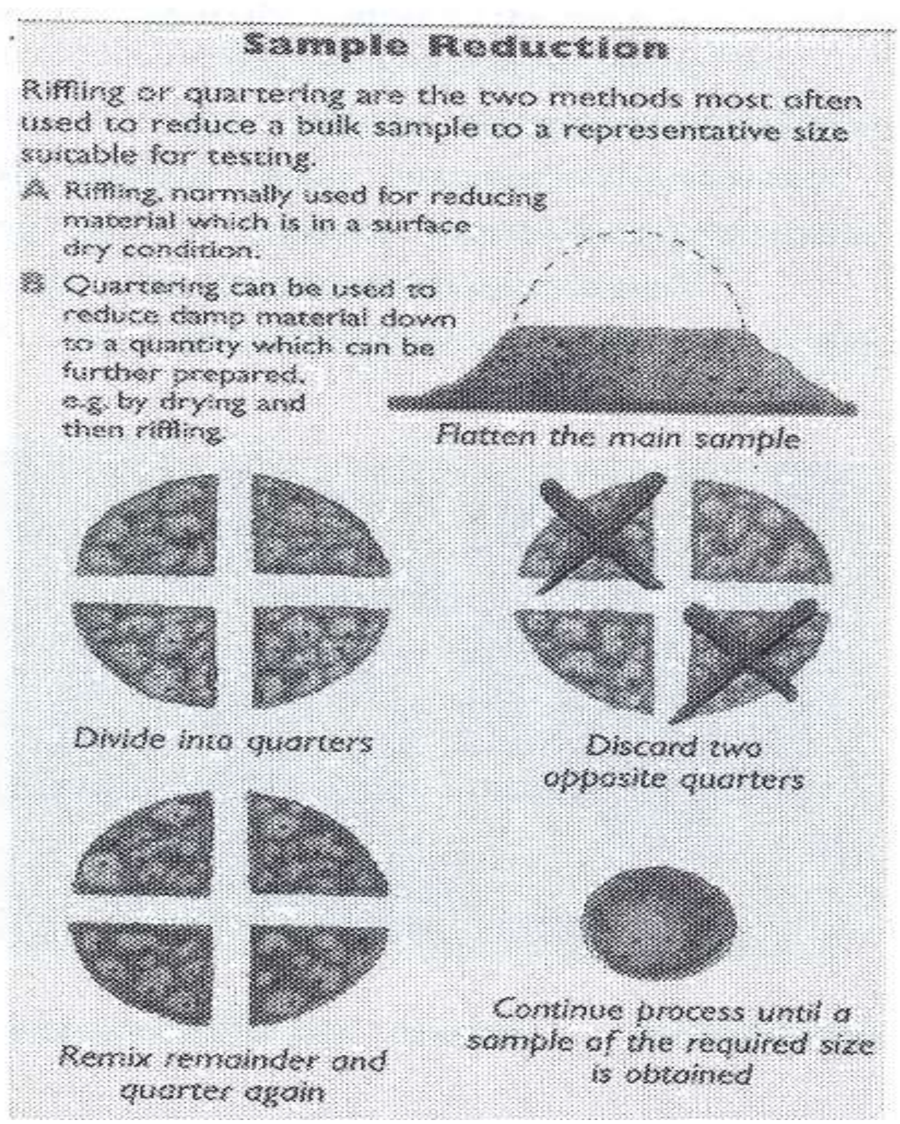

Figure 14: Sample Quartering for Testing Coarse Aggregates

Procedure for Grading Fine Aggregates

1. Weigh 2 Kg of a sample of fine aggregates.
2. Quarter the sample using a riffle box.
3. From the quartered sample take 500gm.
4. Weigh the empty sieve and record the data.
5. Place the pan to the bottom of the sieve shaker and put the other sieves in to the pan with increasing opening sizes of the sieve.
6. Place 500gm of sample on the top of the sieve (having large opening size)
7. Shake the sample about 2 minutes in a sieve shaker.
8. Weigh each sieve together with the aggregate retained on it.
9. Calculate the weight retained in each sieve.
10. Fill in the gradation table below and compute the fineness modulus.

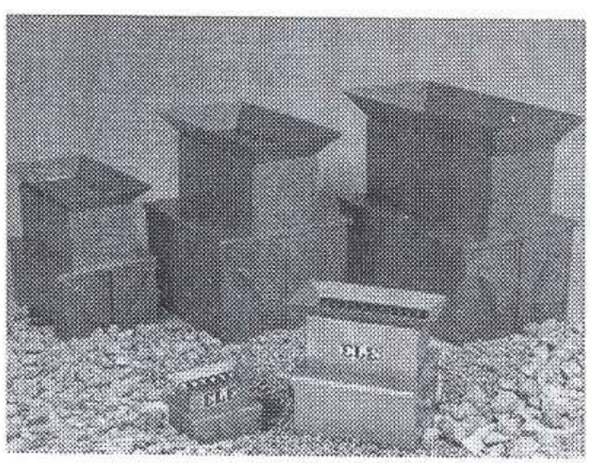

Figure 15: Riffle Box for quartering fine aggregates

Figure 16: Sieve shaker with series of sieves

Table: Gradation of Aggregates

Calculation

$F.M = \frac{\sum cummilative\ coarser\ (\%)}{100}$,

Where:

F.M= the fineness modulus of the aggregate

Note:

1. The grading or particle size of coarse aggregates should be in the limits specified in the above tables for aggregates satisfying Ethiopian standards.
2. Note that the values of intermediate sieves are not included in the determination of Fineness Modulus.

A.6 Moisture Content of Aggregates

Objective

The objective of this test is to determine the moisture content of fine and coarse aggregates.

Theory

It is well known to engineers that water-cement ratio affects the workability and strength of concrete specimens. A design water-cement ratio affects is usually specified based on the assumption that aggregates are inert (neither absorb nor give water to the mixture). But in most cases aggregates from different cases do not comply with this i.e. wet aggregates give water to the mix and drier aggregates (those with below saturation content) take water from the mix affecting, in both cases, the design water-cement ratio and therefore the workability and strength of the mix. In order to correct for these discrepancies, the moisture content of aggregates has to be determined.

Apparatus

- ✓ Balance
- ✓ Dish
- ✓ Oven
- ✓ Trowel

Procedure

1. Weigh a sample of 2Kg coarse aggregate and 500gm fine aggregate separately (A).
2. Oven-dry the samples for about 24 hours with a temperature 105^0C-110^0C.
3. Remove the samples from the oven and place them on the desiccator for about an hour in order to cool without absorbing water from the atmosphere.

4. Weigh the aggregates separately (oven dry weight, B).
5. Calculate the aggregates separately.

Calculation

$$w(\%) = \frac{A-B}{B} X100,$$

Where:

w= Moisture content (%)

A= weight of original sample (g)

B= weight of oven dry sample(g)

A.7 Unit Weight of Aggregates

Objective

This method is used to determine the unit weight of course, fine and mixed aggregates.

Theory

Unit weight can be defined as the weight of a given volume of graded aggregate. It is thus a density measurement and is also known as bulk density. But this alternative term is not a good choice. The unit weight effectively measures the volume that the graded aggregate will occupy in concrete and includes both solid aggregate particles and the voids between them. The unit weight is simply measured by filling a container of known volume and weighing it. Clearly, however, the degree of compaction will change the amount of void space, and hence the value of the unit weight. Since the weight of the aggregate is dependent on the moisture content of the aggregate, constant moisture is required. Oven-dry aggregate is used in this test.

Apparatus

- ✓ Balance
- ✓ Tamping rod
- ✓ Measure- a cylindrical metal measure, provided with handles. It shall be watertight, with top and bottom true and even and sufficiently rigid to retain its form under rough usage.

Table 7: Dimensions of measure

Capacity, [lit]	Inside Diameter, [mm]	Inside Height, [mm]	Min. Thickness of Metal, [mm]		Max. Nominal Size of Aggregate [mm][a]
			Bottom	Wall	
3	155 ± 2	160 ± 2	5.0	2.5	12.5
10	205 ± 2	305 ± 2	5.0	2.5	25.0
15	255 ± 2	295 ± 2	5.0	3.0	37.5
30	355 ± 2	305 ± 2	5.0	3.0	100

Compact Weight Determination

Rodding Procedure (applicable to aggregates of 40mm maximum size)

1. Fill the measure one-third full and level the surface with the fingers. Rod the layer of aggregates with 25 strokes of the tamping rod evenly distributed over the surface. Fill the measure two-thirds and rod as above. Finally, fill the measure to overflowing and again rod as above.

2. Level the surface of aggregates with fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregates approximately valance the larger voids in the surface below the top of the measure.
3. In rodding the first layer, do not allow the rod to strike the bottom measure forcibly. In rodding the second and third layers, use only enough force to cause the tamping rod to penetrate the previous layers of aggregate.
4. Weigh the measure and its contents and record the net weight if the aggregate. Divide this weight by the volume of the measure. The result id the compact unit weight of the aggregates.

Jigging Procedure (applicable to aggregates with max. size greater than 40mm and nit exceeding 100mm)

1. Fill the measure in three approximately equal layers as described above compacting each layer by placing the measure on a firm base, such as cement –concrete floor raising opposite sides alternatively about 5cm, and allowing the measure to drop in such a manner as to hit with sharp slapping blow. The aggregate particles then arrange themselves in a densely compacted condition.
2. Compact each layer by dropping the measure 50 times in the manner described above, 25 times on each side.
3. Level the surface of the aggregate with fingers or a straight edge.
4. Weigh the measure and its content and record the net weight of the aggregate. Divide this weight by the volume of the measure and the result if the compact unit weight.

Weight Determination

Shoveling Procedure (applicable to aggregates having a maximum size of 100mm or less)

1. Fill the measure to overflowing by means of a shovel scoop; discharge the aggregate from a height not exceeding 50mm above the top of the measure. Take care to prevent segregation of particle sizes of which the sample is composed.
2. Level the surface of the aggregate with fingers or a straight edge as in the above procedures.
3. Weigh the measure and its content and record and net weight of the aggregate. Divide this weight by the volume of the measure to get the loose unit weight

References

Amnon Katz, “Properties of Concrete made with Recycled Aggregate from partially Hydrated Old Concrete”, Civil Engineering Department of the Israel Institute of Technology, Concrete and Cement Research Publication, 2003

C. S. Poon, S. C. Kou and L. Lam, “Use of Recycled Aggregates in Molded Concrete Bricks and Blocks”, Department of Civil and Structural Engineering of the Hong Kong Polytechnic University, 2002

How-Ji Chen, Tsong Yen and Kuan-Hung Chen, “Use of building rubbles as Recycled Aggregates”, Department of Civil Engineering of the National Chung-Hsing University, Concrete and Cement Research Publication, 2003

Ilker Bekir Topcu and Selim Sengel, “Properties of Concrete produced with waste Concrete Aggregate”, Civil Engineering Department, Osmangazi University, Cement and Concrete Research, 2002

Mindess, Sidney & Young, J. (2017). Concrete /Sidney Mindess, J. Francis Young. Serbiula (Sistema Librum 2.0). https//www.researchgate.net/publication/445528891_concrete_sideny_mindess_j_Francis_Young

Mirjana Malešev, Vlastimir Radonjanin and Snežana Marinković, “Recycled Concrete as Aggregate for Structural Concrete Production”, 2010

P. Kumar Mehta, “Reducing the environmental impact of concrete”, Civil Engineering Department at the University of California, Berkeley, 2001

Salomon M. Levy, Paulo Helene “Durability of recycled aggregates concrete: a safe way to sustainable development”, Concrete and Cement Research Publication, 2004.